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Recovering Vacuum Drying Exhaust Latent Heat by Steam Recompression with a Jet Pump

Xuanyou Li[1], Ling Gao[2], Rongfeng Sun[1] and Liguo Yang[1]

1. Energy Research Institute, Qilu University of Technology (Shandong Academy of Sciences), 250014, No 19, Keyuan Road, Jinan, Shandong, China
2. Jinan Fruit Research Institute All China Federation of Supply and Marketing Co-operatives, No. 24 East Road of Yanzi Mountain District, Jinan, Shandong, China
Email: yanglg@sderi.cn

Abstract. Recovery of latent heat is one of the most efficient methods to reduce drying energy consumption. This paper presents a system to recovery exhaust latent heat for vacuum drying. Replacing water with heat conduct oil, a hydraulic Jet was employed to evacuate the dryer and compress the exhaust vapour. The heated vapour, which is increased its temperature and pressure by means of recompression, was transferred to the vacuum dryer as the heat source through a heat pipe. This design was confirmed by a series of experiments with oil sludge.

1. Introduction

Because of the obvious advantages of high drying rate and high product quality, vacuum drying has been widely used in food, chemical, electronic and pharmaceutical industries[1~3]. Due to the low drying temperature and oxygen lack environment, vacuum drying is particularly suitable for thermally sensitive materials, such as fruits, bio-products, foods[4~6]. However, including vacuum, the drying is also a high energy consumption process[7]. No matter what kind of drying method is used and no matter how drying efficiency is achieved, to evaporate the moisture, at least the Corresponding latent heat is out to be supplied. Among the heat input to the dryer, a part is used to heat the material and moisture, while the vast majority is used for the evaporation of water. For instance, it is more than 6 times of heat for water evaporation than for heating, under the condition of 1 atmosphere and 20 ℃ initial temperature. So, one of the most efficient ways to thrift drying energy is to recover the latent heat of vapour. Almost pure steam discharge provides a good condition to recover the latent heat of vacuum drying[8]. At present, heat pump and mechanical steam recompression (MVR) are the possible technical methods to perform the latent heat thrift. The heat pump pumps the waste heat from the secondary vapour to heat the drying media. However, a heat pump vacuum drying is limited by the heat pump's working temperature (until now the maximum temperature is within 85 ℃[9]), single capability and heat source. Literature reviews on vacuum heat pump drying reveal only a few of research work[10, 11]. MVR sends the recompressed secondary vapour to the dryer as the heat source, after increasing the temperature and pressure by means of recompression[12, 13]. Despite the wide usage in the field of evaporation and crystallization, there are still only a few attempts to apply MVR on the drying process[14, 15]. The application of MVR on vacuum drying is even blank. One of the main obstacles is that most vacuum drying systems use electricity as an energy resource. On the basis of mechanical steam recompression, this paper proposes a secondary vapour latent heat recovery design for vacuum drying. Taking the factors of the explosion, fire, damage from dust and so on into consideration, a hydraulic jet was employed to evacuate the dryer and compress the secondary vapour. To transfer the upgraded secondary vapour latent heat to be the heat source of drying, a so-called 'separated heat pipe' was designed to connect the liquid tank and the dryer. Meanwhile, a unique design of vacuum dryer with inner tubes was carried out to utilize the recompressed secondary vapour.

2. System Design

The schematic diagram of the vacuum drying with latent recovery is shown in Figure1. The system consists of material, secondary vapour and heat media flow paths. Raw material flows into the pre-heating tank (3, in Figure1) to get its temperature increase. Then the material goes to the vacuum dryer to evaporate its moisture. In both stages, material obtains heat from the heat source by indirect transfer. Finally, the dried product discharges from the vacuum dryer.

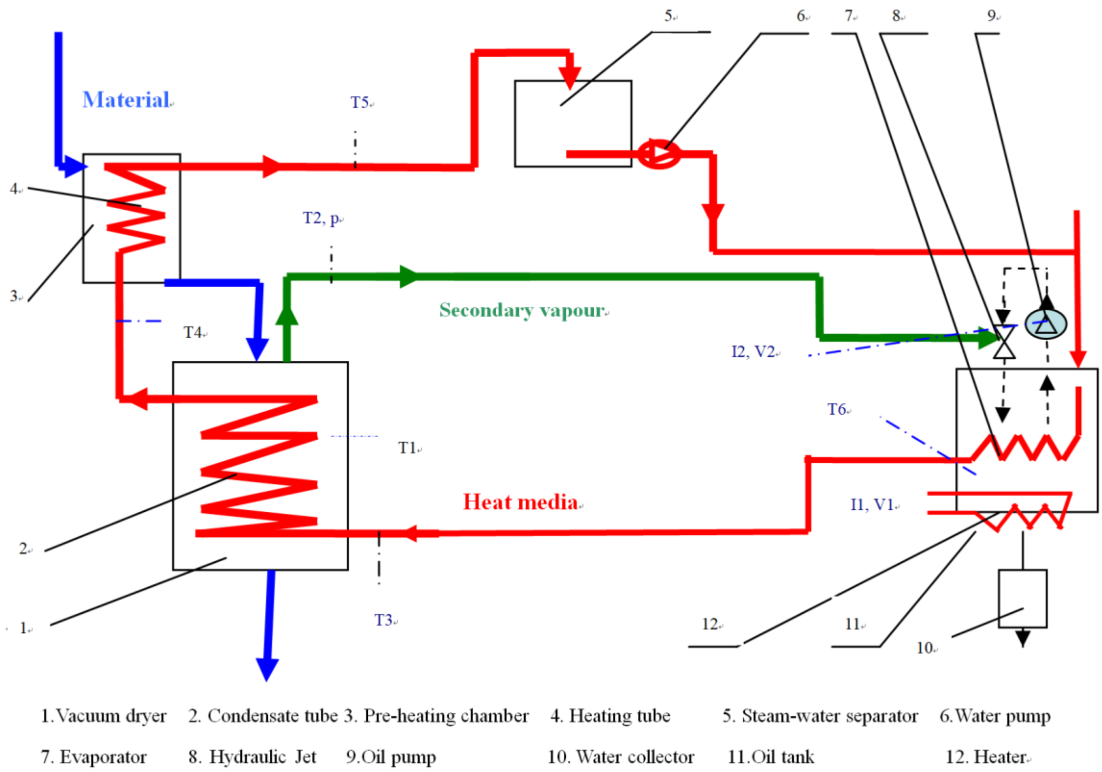

Figure 1. Schematic Diagram of the Designed System

2.1. Dryer

Different from the traditional vacuum dryer, in order to re-use the waste latent heat, the electric or high pressure steam heat source has to be substituted by a low pressure steam (generally the saturated temperature is less than 100 ℃) in our dryer. As a result, the heat radiating from the steam to material is not sufficient for evaporation. To compensate for the shortcomings arising therefrom, this work carried out a new design of vacuum dryer. This dryer assembles small-diameter (15~25 mm) inner heat tubes to increase the heat transfer area. Vibration material transport model allows the dryer continuous operation with only less power consumption. Two pairs of valves are assembled at both inlet and outlet, which alternatively switch on and off to keep the vacuum in the dryer chamber.

2.2. Secondary Vapour

The initial objective of this work is to dry the nature oil sludge, which contains about 10% nature oil. So, any mechanical method to draw the waste gas is dangerous. Meanwhile, the equipment and operation costs have to be kept on a low level for the low added raw material. Therefore, the hydraulic jet was selected to be the evacuating element (7, in Figure 1), showing in Figure 2[14]. Obviously, the evacuated secondary vapour undergoes a pressure increasing process from the inlet to the outlet of a jet. It means that the pressure of evacuated saturated steam rises from negative to atmospheric pressure. If the temperature of media liquid is higher than 100 ℃, as the saturated steam, then vapour escapes with a higher temperature, after obtaining pressure energy from the media liquid. While, if the temperature of media liquid is less than 100 ℃, the vapour condensates by releasing its latent to the media liquid. Thus, a cheap hydraulic jet in this design is employed as not only an evacuator, but also a steam compressor, which is utilized for latent heat recovery and reducing running costs. To limit the precipitation of light components, this design adopted the second case as the operation mode.

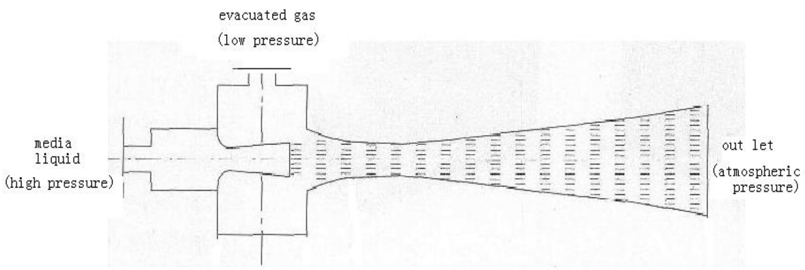

Figure 2. A hydraulic jet

Despite the general usage, water is not competent to such a system because of the high running temperature, which is may reach to 100 ℃. So, heat conducting oil becomes a superior selection, because its boiling point is higher than 350 ℃ and no boiling under at a vacuum of -0.09MPa.

An electric heater is assembled at the bottom of the oil tank (11, in Figure1) to decrease the viscosity at the initial when the system starts and compensates the heat losses to the environment in the operation process.

A water tank assembled at the bottom of the oil tank is used to separate thermal conducting oil and water.

A liquid pump (9, in Figure1) pumps the oil to the hydraulic jet to drive the evacuator. The electric energy supplied to the pump shifts to heat, finally provides energy for drying. It carries out one of this design’s highlight advantages that the pump is not only a liquid driver, but also a drying energy source provider.

The input of electrical power for the liquid pump and the latent heat release from secondary vapour make the temperature of conducting oil increase. This additional heat gathers in the oil tank is then carried to the dryer by the separated heat pipe.

2.3. Heat Media Flow

The negative pressure in the heat pipe makes the filled water to evaporate in the evaporator (12, in Figure1) at a relatively low temperature (generally, start at about 40 ℃). The steam in the heat pipe condensates in the condensate tube (2, in Figure1). The condensate tubes installed in the vacuum dryer (1, in Figure1) are used as an inner heater. The condensation in the heat pipe keeps release its heat and decrease its temperature in the preheat chamber (3, in Figure1). A water pump (6, in Figure1) installed after the steam-water separator (5, in Figure1) is used to force the loop flow.

2.4. Experimental Set

According to the above scheme, an experimental set was designed, manufactured and tested in the Qilu University of Technology (Shandong Academy of Sciences), showing in Figure 2. Oil sludge with an initial moisture content of 80% was used as the raw material. The required final moisture content of oil sludge is 30%.

The material temperature in the dryer, outlet temperature and pressure of the secondary vapour, temperature in the oil tank, electric voltages and currencies of liquid pump and electric heat (12, in Figure1), and so on were measured and recorded. The measured positions are shown in Figure1.

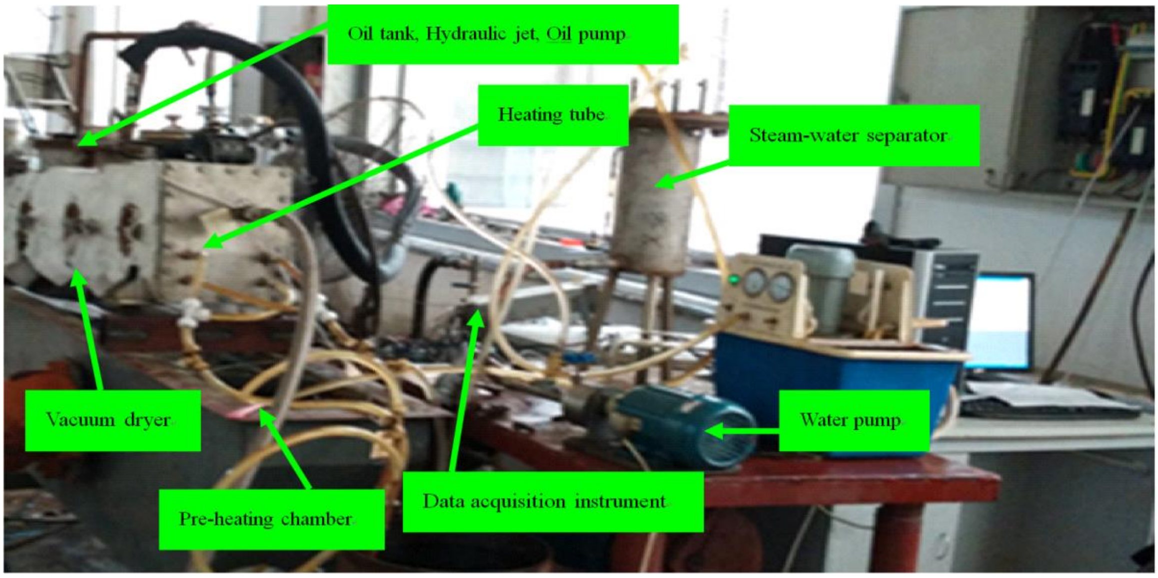

Figure 3. Experiment set

3. Results and Discussion

The results of tests verified the feasibility of the above design that drying system, including the heat pipe, works with extreme stability.

Table 1. Operation Parameters

	Point	A	B
T1(℃)	dryer	75.28	79.8
T2(℃)	Secondary vapour outlet	74.02	76.73
T3(℃)	Media in dryer	97.78	92.15
T4(℃)	Media leaving dryer	77.10	81.45
T5(℃)	Media leaving pre-heating chamber	50.07	60.90
T6(℃)	Oil in tank	101.22	93.11
P(Mp)	Pressure in dryer	-0.065	-0.055
V1(v)	heater	380	380
I1(A)	heater	3.15	1.26
V2(V)	Oil pump	380	380
I2(A)	Oil pump	6.51	6.22

Table 1 shows a pair of operation data when the drying process went to stable, about 36 minutes from the beginning. Theoretically, if the whole latent heat was recovered and the heat losses were neglected, the input heat is used only to increase the temperature of raw material. The results of the experiments showed that it needs 0.9 kg of equivalent latent heat of vaporization to remove 1 kg of water. This is indicative of a large optimization space of the system on heat isolation and the configuration of accessory. Nevertheless, comparing the equipment costs, this design has significant economic advantages.

4. Conclusions

- On the basis of machinery steam re-compression, a unique system designed for vacuum drying exhaust vapour latent heat recovery was experimentally verified.
- A cheap hydraulic jet is able to be taken as both evacuator and low pressure steam re-compressor.
- An oil pump in this design plays not only a liquid driver for a hydraulic jet, but also a drying energy source provider.

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